PMIC
Final Report
for
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THERMAL CONDUCTIVITY MEASUREMENTS OF SANDSTONE SPECIMENS

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PURCHASE ORDER NUMBER 081213

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THERMAL CONDUCTIVITY MEASUREMENTS OF SANDSTONE SPECIMENS

WORK CONDUCTED FOR JOSEPH A CESARE & ASSOC.
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Precision Measurements and Instruments Corporation (PMIC) measured the thermal conductivity of Sandstone test specimens. Measurements were performed with a guarded hot plate technique based on ASTM standard C-177, performed in dry nitrogen. Results are presented in the table. Information on thermal conductivity measurement techniques is also included.

Specimen Description

Joseph A Cesare & Assoc. provided the following specimens:

Material	Nominal Length	Nominal Width	Nominal Thickness
Sandstone	6"	6"	1.22"
Sandstone	6"	6"	1.34"

The specimens were measured in the thickness direction.

Test Procedure

- Specimen Check-In

The specimens were received on February 23, 2009, via UPS Ground. The specimens were inspected for damage. No specimen damage was observed. It was noted that the thickness varied by ~0.12" (10%) between specimens and up to 0.014"- 0.018" between points on a given specimen. The specimens were labeled and stored in a secure environment.

- Specimen Preparation

The specimens were tested as received.

- Specimen Conditioning

The specimens were tested as received.

- Thermal Conductivity Measurements C-177

The main features of the test apparatus are described in ASTM C-177. The center layer consists of a guard heater surrounding (in plane) a metering heater. The guard is maintained to within 0.1°C of the metered heater so that all heat generated flows up and down into the specimens. The bottom and top plates are kept at lower temperatures than the heater so that a gradient, ΔT, is established across each specimen. The temperature differential across the apparatus was maintained at 30°C. Multiple thermocouples at the center top and center bottom of each specimen measure the ΔT. All testing was conducted in a dry nitrogen environment at nominal temperatures of -18°C, 22°C and

49°C (0°F, 72°F and 120°F). Silicone rubber pads, 1/8" thick, were placed between the specimens and adjacent contact surfaces to assure uniform contact with the fixture. The specimens were placed with the smooth side towards the heat source in the apparatus.

- Analysis

When the metered and guard areas had been at the desired steady state conditions for sufficient time, 40 minutes of data were logged at 2-second intervals. The first 20 -minute data set and the second 20 -minute data set were analyzed separately to assure that no significant temperature drift occurred during logging. The output from the multiple thermocouple sets was then averaged to produce the temperature data used for the thermal conductivity calculations. The analysis is based on solution of Fourier's First Law of one-dimensional conduction:

$$k = \frac{q}{A} * \frac{dX}{dT}$$

where: k is the conductivity, W/m-K
q is the heat flow, Watts
A is the cross-sectional area of the specimen, m^2
dX is the specimen length, m
dT is the is the temperature difference across the specimen, °C or K

Uncertainty

The uncertainty in the measurement was calculated using the following RMS method:

$$\omega_R = \left[\left(\frac{\partial R}{\partial x_1} \omega_1 \right)^2 + \left(\frac{\partial R}{\partial x_2} \omega_2 \right)^2 + \ldots + \left(\frac{\partial R}{\partial x_n} \omega_n \right)^2 \right]^{1/2}$$

where: ω_R is the overall measurement uncertainty
x_i is each measured input
ω_i is the estimated uncertainty of each measurement input, x_i
$\partial R/\partial x_i$ is the weighted contribution of each input, x_i

The estimated uncertainties are:
I ~ 0.05% of reading, Amps
V ~ 0.05% of reading, Volts
A ~ 1%, m^2
dX ~ 0.000254 m (0.01 inch)
T ~ 0.25°C

Thermal Conductivity Test Results

Thermal properties are presented in **Table 1**, in several systems of units. The actual average specimen temperature is also listed. The R-Value is based on the average thickness of 1.284" (0.107').

The uncertainty based on the method shown above is ~2.3% at the three temperature points. However, this does not take into account the inconsistent specimen thickness. It was also noted that the material properties resulted in inconsistent temperature gradients through the specimens at different points.

Table 1, Through-Thickness Thermal Properties
Based on ASTM C-177

Sample ID	Nominal Temperature (°C)	-18	22	49
Sandstone	Tested Temperature (°C)	-19	21	48
	Conductivity (W/m-K)	2.8	2.8	2.9
	Tested Temperature (°F)	-1	71	119
Tested in a dry nitrogen gas environment	Conductivity (Btu/hr-ft-°F)	1.6	1.6	1.7
	Conductivity (BTU-in)/(hr-ft^2-°F)	19	20	20
	R-Value (hr-ft^2-°F/Btu) @ 1.284"	0.067	0.065	0.063

Please contact our technical staff at (541) 753-0607 with any technical questions.

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Precision Measurements and Instruments Corporation hereby claims that test results are obtained by techniques based on relevant ASTM standards, calibrations with NIST standard reference materials and/or published procedures. Thus, we accept no liability for test results beyond the cost of the contract rendered.

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